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The relationship between the midpoints connecting the tibial attachments of the anterior and posterior cruciate ligaments and the transepicondylar axis: In vivo three-dimensional measurement in the Chinese population

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Background: To determine the relationship between the midpoints connecting the tibial attachments of the anterior and posterior cruciate ligament (ACL and PCL, APCL line) and the transepicondylar axis (TEA) in normal healthy Chinese, as well as the comparison with other rotational lines.

Methods: Left knees of 17 male and 15 female healthy Chinese volunteers were scanned by magnetic resonance imaging (MRI) and computer tomography (CT) respectively. 3D contours of each knee, the tibial attachments of ACL, PCL, the medial and lateral collateral ligaments were reconstructed separately from CT and MRI data. Using an iterative closest point algorithm, we superimposed them individually. The APCL line, the tibial posterior condylar line (PC line), the medial third of the tibial tubercle (1/3 line), the Akagi's line, and the midsulcus of the tibial spine (Midsulcus line), the clinical and surgical TEA (CTEA and STEA) were determined. The paired intersection angles of them were measured.

Results: The mean angle CTEA with APCL line, Akagi's line, Midsulcus line, 1/3 line, and PC line, respectively, was 90.3° ± 2.9°, 95.0°±3.0°, 94.0° ± 3.9°, 102.4° ± 2.7°, and 87.1° ± 3.0°. The APCL–CTEA was significant different than other angles ($p < 0.001$). The mean angle STEA to the above lines, respectively, was 94.8° ± 3.1°, 99.4° ± 3.1°, 98.5° ± 4.0°, 106.9° ± 2.9°, and 91.6° ± 3.2°. The PC line-STEA was significantly different than other angles ($p < 0.05$).

Conclusions: APCL line was the closest perpendicular to the CTEA in normal Chinese subjects comparing with other rotational lines.

1. Introduction

Malrotation of the femoral and the tibial components in total knee arthroplasty (TKA) is closely related to anterior knee pain, joint stiffness, and polyethylene wear [1–5]. The transepicondylar axis (TEA) [6] is widely accepted as the femoral rotational reference, but the rotational reference of the tibial component is still debatable. Commonly used methods of determining the tibial rotational reference are the tibial posterior condylar line (PC line) [7], the medial third of the tibial tubercle (1/3 line) [8], the Akagi's line [9], and the midsulcus of the tibial spine (Midsulcus line) [10]. However, all of these methods have shortcomings, including excessively external rotation [9,11], osteophyte influence [7], or two-dimensional (2D) measurement method [12].

Studies using magnetic resonance imaging (MRI) and anatomy have shown that the anterior cruciate ligaments (ACLs) and the posterior cruciate ligament (PCL) also participate in TEA formation, cooperating with the medial and lateral collateral ligaments (MCL and LCL) [13]. Cadaveric researches have shown that cutting the ACL or PCL has an effect on internal or external rotation of tibia [14–17]. All of these indicated that ACL and PCL controlled the tibial rotation orientation and had a relationship with the anteroposterior axis of the tibia. If it was not taken into consideration, ACL and PCL would certainly impinge on the intercondylar notch, and would be a non-isometric structure during knee flexion.

We proposed a hypothesis that a line passing through the midpoints of the tibial attachments of ACL and PCL (APCL line) was the true tibial

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rotation orientation. If this hypothesis was correct, the APCL line should be approximately perpendicular to the TEA and better than other lines. The purpose of this study was to verify the hypothesis by using three-dimensional (3D) measurements based on the CT and MRI data in normal healthy Chinese. The relationships between the above-mentioned lines and the APCL line were also to be determined. Identifying the appropriate tibial plateau rotational orientation would be helpful to the posterior sloped cut and the tibial baseplate implant.

2. Materials and methods

2.1. Specimen preparation

Twenty male and 20 female healthy Chinese volunteers were enrolled; none of them has knee disease. Radiographic examination of anteroposterior (AP) and lateral views of the left knee were performed. Femorotibial angle was measured using a goniasmometer (accurate to single figures). Due to knee varus we excluded one man and one woman. In the subsequent examination by CT and MRI, we excluded one man and four women due to lack of medial sulcus, and excluded one man due to vague ACL. Finally, 17 males (27.8 $\pm$ 3.5 years; 24–40 years old) and 15 females (24.2 $\pm$ 0.8 years; 23–26 years old) were involved in this study. All volunteers were informed of the risk of radiographic exposure during CT scans and signed informed consent forms for knee CT and MRI. The study protocol was approved by our Institutional Review Board.

2.2. Image acquisition

For CT scanning, each left knee was fixed in a polyfoam brace. The second toe was pointed upwards and the knee was kept in an extended position parallel to the CT bed. CT scan (0.6 mm/slice; Siemens, Germany) was performed from distal femur to ankle joint. For MRI scanning, each left knee was examined in the naturally extended position with neutral rotation using an MR scanner (3.0 T; Siemens, Germany: t1 sequence, section thickness one millimeter, field of view 130 $\times$ 130 mm^2). Sagittal and axial views were scanned. All image data were saved as DICOM (Digital Imaging and Communications in Medicine) files on a personal computer.

2.3. Reconstruction of 3D surface model

Three-dimensional surface models of the femurs, tibia, and fibula were reconstructed from the CT data using the marching cube algorithm, which is a well-known, efficient, cell-by-cell method for 3D reconstruction of anatomical structures [18]. Geometric models were visualized using the original program based on the Visualization Toolkit (Kitware, Clifton Park, New York). The contours of the distal femur and the origins of MCL and LCL were extracted from the axial MR data using a semi-automatic segmentation process. We marked the medial layer of the LCL and the most prominent point on the lateral epicondyle, as well as the medial sulcus and the most prominent point in a same scanning plane on the medial epicondyle. (Figure 1(A), (B)) The contours of the proximal tibia and the insertions of ACL were extracted from the sagittal MR data. The axial contours of PCL in the posterior condylar notch were extracted from the reconstructed axial plane originating from the sagittal MR data (Figure 1(C), (D)). Therefore, the contours of the medial epicondyles, the lateral epicondyles, the medial sulcus, ACL, and PCL were marked on the 3D models of MRI (Figure 2).

Berger et al. [6] proposed two types of TEA: clinical TEA (CTEA) and surgical TEA (STEA). The corresponding anatomical landmarks were the lateral epicondyle to the medial epicondyle (CTEA), and the lateral epicondyle to the medial sulcus (STEA). We divided all data into a CTEA and an STEA group which were 3D reconstructed. All the mentioned rotated lines were compared to CTEA and STEA.

2.4. Shape registration

The iterative closest point algorithm (ICP) was one of the most well-developed methods for surface-based registration [19]. In this method, the 3D surface models from CT and MRI were superimposed automatically by software. In this study, the accuracy of the ICP algorithm was in translation of 0.5 mm, and rotation one degree. Using this method, the medial sulcus, the medial and lateral epicondyles, and the ACL and PCL were labeled on the articular surface of 3D of CT. The midpoints of ACL and PCL were calculated automatically by the software (Figure 3).

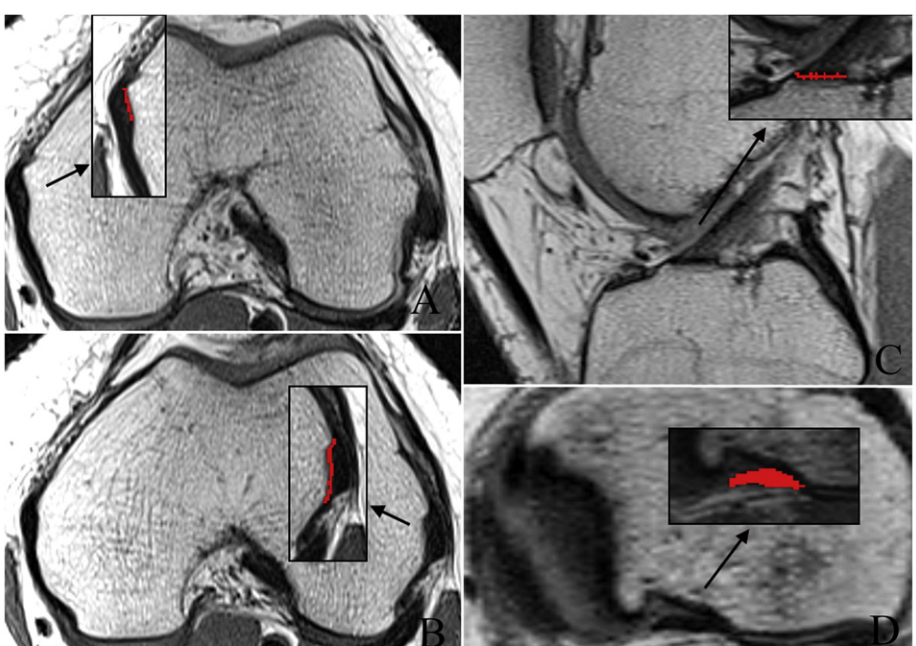

Figure 1. The sulcus and the most prominent point on the medial epicondyle (A), the intermediate layer of the LCL and the most prominent point on the lateral epicondyle (B), the attachment of ACL (C), and the axial contour of PCL in the posterior condylar notch (D) were marked.